

## Experiment 2 — Electric Fields: Prelab

PHYS 231: Fundamentals of Physics: Electricity and Magnetism  
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### Prelab

Charges are the basic unit of study for electricity. Protons that are in the nuclei of atoms are positively charged, and electrons that orbit the nuclei are negatively charged. Electrons and protons have an equal and opposite charge. One electron has a charge of  $-1.602 \times 10^{-19}$  coulombs, or  $-1.602 \times 10^{-19}$  C, and one proton has a charge of  $+1.602 \times 10^{-19}$  C. Just like the Earth exerts a force on the moon and vice versa, charges exert forces on other charges that are separated in space. However, gravitational forces are attractive in nature whereas electrical forces, or Coulomb forces, can be attractive or repulsive. Like charges repel and opposite charges attract. The amount of force between two charges is given by Coulomb's Law:

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

Where  $\epsilon_0$  is a constant called the permittivity of free space,  $q_1$  and  $q_2$  are the charges and  $r$  is the distance between the two charges. The direction of the force on one charge is either toward (attractive) or away (repulsive) from the other charge. The electric force is a vector quantity, just like other forces that you have learned about, since it has magnitude and direction.

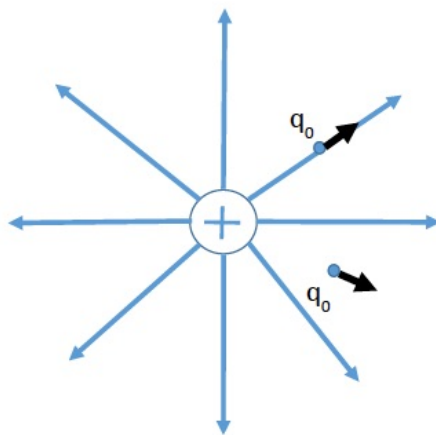


Figure 1: A positive charge has an electric field around it depicted by the blue arrows. The density of lines is greater closest to the positive charge, indicating a larger electric field strength. A test charge,  $q_0$ , can be placed around the positive charge to map out the electric field lines.

Since a charge has a force exerted on it due to the electric field, that force can do work on the charge ( $\vec{F} \cdot \vec{d} = W = \Delta U$ ) [1]. The amount of electric potential energy  $U$  that a charge has is the amount of energy it would gain or lose if it moved from the point  $a$  to point  $b$ . It depends on where the charge is within the electric field. The electric potential  $V$  for a charge is the electric potential energy divided by the charge.

Go to: [https://phet.colorado.edu/sims/html/charges-and-fields/latest/charges-and-fields\\_en.html](https://phet.colorado.edu/sims/html/charges-and-fields/latest/charges-and-fields_en.html)

Check the boxes Electric Field, Values, and Grid. Put a 1 nC positive charge on the grid. The field direction is indicated by the arrows. The electric field strength is indicated by the intensity of the arrows (brighter white  $\rightarrow$  higher electric field strength, dimmer white  $\rightarrow$  lower electric field strength). The electric field strength should fall off as  $\frac{1}{r^2}$  for a singular charge. You can add a yellow sensor at any point on the grid which will display the electric field strength at that point.

1. Draw a sketch of the electric field lines for the 1 nC positive charge.
2. Use the voltmeter by dragging it out of the box and onto the grid to find points that are all at the same potential (equipotential lines). Sketch and label a few equipotential lines (i.e., find points that are all at 12 V) on your drawing. How do these equipotential lines compare to your electric field lines?
3. Add a negative point charge to the grid.
4. Draw a sketch of the electric field lines for the two charge configuration.
5. Create another charge configuration and sketch the electric field lines.

## References

- [1] Young, Hugh and Roger Freedman, *University Physics with Modern Physics*, 14<sup>th</sup> edition, Pearson: San Francisco, 2016.
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## Experiment 2 — Electric Fields

PHYS 231: Fundamentals of Physics: Electricity and Magnetism

*by Dr. James E. Parks*

## The Cenco Overbeck Apparatus

### Objectives

The objectives of this experiment are to:

1. Study the concept of an electric field and how it is defined.
2. Learn how to measure the electric field strength.
3. Study the relationships between the electric potential and electric field strength.
4. Study different types of electrode configurations and their accompanying electric field patterns.

### Method

A set of the Cenco Overbeck apparatus is used to map out electric fields and to measure the electric field strength at various points. Electric fields are produced in a conducting, but resistive medium (conducting paper) by the application of a source of *emf* to two conducting electrodes. The resistive medium is a conducting paper with a finite resistance made by impregnating it with carbon. The conducting electrodes have been made by painting various shapes and configurations on the paper with silver conducting paint. The conducting, metallic electrodes are connected to an *emf* source which is a variable DC power supply and is used to establish each electrode at some desired equipotential value.

The electric field strength is measured first by measuring the electric potential with a digital voltmeter. Points are found that are at the same potential and lie on a line called an equipotential line. Once the equipotential lines have been found, the electric field lines, which are perpendicular to the equipotential lines, may be found. The strength of the electric field at any point is found by measuring the potential difference between adjacent equipotential lines and dividing by the distance between them. The distance between the lines is taken along the electric field lines which are perpendicular to the equipotential lines. Hence, the distance taken is the shortest distance between the equipotential lines at the point of measurement and therefore is measured in a direction in which the potential change is the greatest.

## Theory

An electric field is defined as a space (field) in which if there is placed a small positive test charge, there will be a force exerted on this test charge. The magnitude of the electric field strength  $|\vec{E}|$  is given by the ratio of this force  $F$  divided by the magnitude of the charge  $q$ , i.e.,

$$\vec{E} = \frac{\vec{F}}{q} \quad (1)$$

The electric field is a vector quantity whose direction is taken to be the direction that this small positive test charge would move. Electric fields are produced by other charges or charge distributions. These are in turn created by the separation of charges by some electromotive force, *emf*, such as a battery or power supply. This is usually done by applying the *emf* to two conducting electrodes. The geometries of the electrodes and their relative positions determine the way in which the charges will be distributed on the electrodes. The charge distribution then determines the electric field strength at various points in space.

If the charge distributions are known, the electric field may be calculated using an extension of Coulomb's law. However, the charge distributions are difficult to find. While it is conceptually easy to place a small test charge in an electric field and find the force on it, it is not practical to do so. The electric field must be measured by other indirect means, such as measuring the electric potential and using relationships between electric potential and electric field strength. Electric potentials can be easily measured with voltmeters if the input impedance of the voltmeter is high enough so that it does not disturb the electric field in which it is placed.

The electric potential is best defined in terms of potential difference since the potential at any point may be set arbitrarily to zero. A potential difference exists between two points in an electric field when work is required to move a charge from one point in the field to the other. The electric potential difference  $V$  between these two points then is defined as the work  $W$  required to move a small positive test charge  $q$  from one point to the other divided by the test charge, i.e.,

$$V = \frac{W}{q} \quad (2)$$

The work and hence the potential difference between the two points is independent of the path that is taken between the two points. Since the potential at one of the points may be arbitrarily set equal to zero, the potential difference and potential at the other point are the same. Using the basic definition of work, in which work  $W$  equals force  $F$  times distance  $d$ , or

$$W = \vec{F} \cdot \vec{d} \quad (3)$$

a relationship between the electric potential  $V$  and the electric field strength  $E$  can be found. While work and potential difference are scalar quantities and are independent of the direction and path that is taken, the electric field strength is a vector quantity and depends on the direction of the force. Therefore, the relationship depends on the direction of the force, so the relationship that is found between  $V$  and  $E$  must also be a directional relationship. In Equation (3) work is a scalar quantity which is equal to the product of two vectors. This scalar product, as it is called, means that the force and distance, or their components, must be in the same direction before being multiplied together. Care must be taken to insure that the integrity of the vector relationships are preserved. A proper relationship between  $V$  and  $E$  may be found by substituting Equation (3) into Equation (2), so that

$$V = \frac{\vec{F} \cdot \vec{d}}{q} \quad (4)$$

Then, by substituting Equation (1) into this result, the potential difference is given by

$$V = \frac{q\vec{E} \cdot \vec{d}}{q} \quad (5)$$

or

$$V = \vec{E} \cdot \vec{d} \quad (6)$$

If  $\vec{E}$  and  $\vec{d}$  are in the same direction, then

$$V = Ed \quad (7)$$

and

$$E = \frac{V}{d} \quad (8)$$

For situations where the electric field is not uniform at different points in space, this equation must be constrained to apply over a small increment of distance  $\Delta d$  where the change in potential is  $\Delta V$ . Then the electric field strength is found by the following equation

$$E = \frac{\Delta V}{\Delta d} \quad (9)$$

Therefore, the electric field strength at a point may be found by measuring the potential difference between two nearby points which lie along a line in the direction of the electric field and dividing by the distance between these two points.

The SI unit of electric field strength is newton/coulomb and is equivalent to volts/meter. More commonly, though, the electric field strength is measured in units of volts/cm, a hybrid of cgs and SI units.

If a test charge were moved in a direction perpendicular to the electric field, no work would have to be done in doing so. This means there would be no change in potential and the charge would be moved along an equipotential line. Therefore, electric field lines and equipotential lines are perpendicular. The potential undergoes no change in a direction perpendicular to the electric field and undergoes a maximum change in a direction parallel to the field.

## Just for Those with an Understanding of Calculus

The electric field's direction is parallel and opposite to the direction in which the electric potential increases the most. In calculus, an operator called the gradient and symbolized by  $\nabla$  is introduced to signify changes that must be made in a direction in which the change is greatest. With this notation, Equation (9) may be written in terms of calculus so that

$$\vec{E} = -\nabla V \quad (10)$$

Where  $\nabla V = \lim_{\Delta s \rightarrow 0} \left( \frac{\Delta V}{\Delta s} \right) \hat{s}$  and  $\Delta V$  is the change in potential,  $\Delta s$  is the distance over which this change takes place, and  $\hat{s}$  is the unit vector which is the direction over which the change in potential is the greatest. The minus sign occurs because the electric field is in the opposite direction to the direction in which the potential is increasing. The symbols  $\lim_{\Delta s \rightarrow 0}$  means that  $\Delta s$  must be very small. Therefore,

$$\vec{E} = -\lim_{\Delta s \rightarrow 0} \left( \frac{\Delta V}{\Delta s} \right) \hat{s}. \quad (11)$$

## Apparatus

The equipment needed for this experiment is shown in Figure 1 and consists of the following:

1. Cenco-Overbeck electric fields mapping apparatus with U-shaped mapping probe
2. Sets of parallel, point, and circle electrode configurations painted on conducting paper mounted to a substrate
3. Pasco PI-9877 variable dc power supply
4. Digital voltmeter
5. Banana plug connecting wires
6. Graph paper
7. Ruler
8. Pencil

## Procedure

1. The experiment will be performed first using a parallel electrode configuration. This configuration yields a space in which the electric field is constant and is the easiest to measure and understand.
2. Examine the apparatus and make sure that it is wired as shown in Figure 1. The apparatus consists of a board on the bottom of which the conducting paper mounted substrate and parallel electrode configuration may be attached. The top side of the board provides for the placement of a sheet of graph paper and has guide pins for the positioning of a template that matches the position of the electrodes on the bottom of the board. The top portion of the board has a terminal on each side which is connected to the two terminals on the bottom side that are attached to the two conducting electrodes. A U-shaped probe provides a mechanism by which the potential may be measured by contacting the conducting paper on the bottom. The corresponding position may then be recorded on the graph paper on the top.

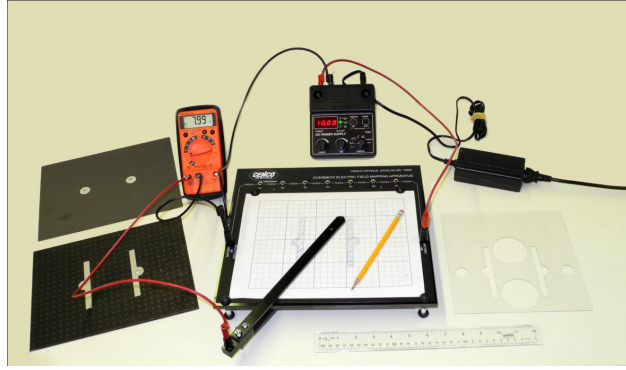


Figure 1: Electric fields experiment using the Cenco-Overbeck field mapping apparatus.

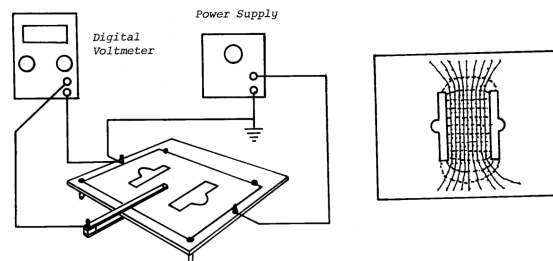


Figure 2: Schematic diagram for electric fields experiment.

3. Turn the digital voltmeter on to the DCV range. (Turning the voltmeter on while holding the range button in and still holding for 2 seconds afterward, will prevent the voltmeter from turning itself off to save power.) Adjust the precision of the readings by repeatedly pushing the range selection button until the range shows only a 0.1 volt precision, i.e. the voltmeter reading rounds off to the nearest 0.1 volt. Check that the digital voltmeter is wired as shown in Figure 2, so that it measures the electrical potential between ground and the free, hand-held probe which will be used to measure the electric potential at various points in the resistive medium. Make sure the digital voltmeter is on and is set to measure a voltage. The range of the voltmeter should be set to measure 0 to 10 volts to a precision of 0.1 volts. The range can be changed by repeatedly pushing the range button and observing the position of the decimal point in the display.
4. Obtain a sheet of graph paper (large 1 cm divisions is best) and attach it to the top of the board. The feet of the board are spring loaded so that if you push down on each corner of the board, a rubber pad will rise up so each corner of the graph paper may be inserted and held down when the spring is allowed to return to its normal position.
5. Position the clear plastic template over the positioning pins and trace the outline of the parallel electrodes. Remove the template.
6. Position the U-shaped probe so that it is between the electrodes near the center. The metal ball of the U-shaped probe should contact the conducting paper. On the topside of the board, you should see a hole in the probe which you can use to make marks on your paper as you take readings. When readings are being made with the probe, it should be squeezed together slightly. Care should be taken to make sure no shearing stresses are placed on the probe and that the probe's indicating circle and contact point are always directly opposite each other.

7. Turn on the power supply and adjust the voltage until the digital voltmeter reads about 5 volts. Make sure the probe is making good contact while doing this.
8. Move the probe left and right and note how the voltage changes.
9. Move the probe to and from you and note how the voltage changes.
10. Note the directions in which the potential increases and decreases the most and the least. Record the observations.
11. Move the probe to the left electrode and note that the potential there is zero. Also note that the potential is zero at every point on the conducting electrode. This results from the arbitrary choosing of the zero point and was done by connecting the ground side of the voltmeter to this electrode. Ground potential is customarily zero.
12. Move the probe to the right electrode and note its potential. Also note that the potential is the same at every point on the electrode. Re-adjust the power supply so that the electrode's potential is 10 volts.
13. Move the probe around until you find a point at one volt potential. Circle that point and repeat this procedure many times until you can construct with certainty the one volt equipotential line. Do not be afraid to go around behind the electrodes to measure the potential and find points. Connect the points with a solid line.
14. Repeat the previous step for the 2, 3, 4, 5, 6, 7, 8, and 9 volt equipotential lines.
15. Draw continuous dotted lines perpendicularly to the equipotential lines and indicate the direction of the electric field lines.
16. Have your instructor designate points on your graph at which you are to calculate the magnitude of the electric field strength. Label them as A, B, C, ....
17. Calculate the electric field strength at one of the indicated points by moving a little distance (**less than 0.5 cm**) to the left along the electric field line and a little distance to the right along the electric field line. Record the electric potential at each of these adjacent points and find their difference,  $\Delta V$ . Measure the distance between the two points to find  $\Delta s$ . Calculate the electric field strength by dividing  $\Delta V$  by  $\Delta s$ . Repeat for each of the other points. Record your results for the points A, B, C, ....
18. What observations can you make concerning the electric field in between the parallel plates and outside the plates?
19. Repeat the experiment for another electrode configuration.
20. After you have completed the experiment, turn off the power supply and the digital voltmeter.

## Questions

1. Write Reflections on your lab today.
2. If the potential is the same everywhere on the conducting electrodes, what is the electric field strength in each electrode?
3. If a volt is joule/coulomb, show that a newton/coulomb and a volt/meter are equivalent.
4. Why is it not possible for two different equipotential lines to cross?
5. Under what conditions will the field between the electrodes of a parallel plate configuration be uniform?
6. Why are the equipotential lines near a conducting surface parallel to the surface? Hint: Since charges are free to move on a conductor, the electric field near a conductor is perpendicular to the conductor's surface.
7. Describe how a uniform electric field might be used to measure distance. Hint: In the parallel electrode arrangement, what parameter(s) varied with distance between the electrodes and what parameter(s) stayed constant?